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Access 5 Project Deliverable

Deliverable Number: CCC004

Title: Step 1 C3 Flight Demo Data Analysis Plan

Filename: CCC004_C3_Data_Analysis_Plan_FINAL.doc

Abstract: The Data Analysis Plan (DAP) describes the data analysis that the C3 Work Package (WP) will perform in support of the Access 5 Step 1 C3 flight demonstration objectives as well as the processes that will be used by the Flight IPT to gather and distribute the data collected to satisfy those objectives. In addition to C3 requirements, this document will encompass some Human Systems Interface (HSI) requirements in performing the C3 flight demonstrations. The C3 DAP will be used as the primary interface requirements document between the C3 Work Package and Flight Test organizations (Flight IPT and Non-Access 5 Flight Programs). In addition to providing data requirements for Access 5 flight test (piggyback technology demonstration flights, dedicated C3 technology demonstration flights, and Airspace Operations Demonstration flights), the C3 DAP will be used to request flight data from Non-Access 5 flight programs for C3 related data products

Limitations on use: The C3 DAP is an approved Access 5 document that reflects the C3 functional requirements documents generated by the C3 WP as defined up to July 1, 2005. Any revisions to the C3 functional requirements should be reflected on the C3 DAP for traceability.

Status: **Access 5-Approved**

Access 5

Command, Control, and Communication (C3) Workgroup

National Aeronautics and Space Administration

with participation by the

Federal Aviation Administration

Department of Defense

Aerospace industry

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Document No.

1-C3-DAP-000

Step 1 C3 Flight Demo Data Analysis Plan

Release: **30 June 2005**

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The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project

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REVISION HISTORY

REVISION	AUTHOR	DATE	LIST OF CHANGES
Initial Release	Ting Tseng	30 June 2005	
01			
02			
03			

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1 Scope

This Data Analysis Plan (DAP) describes the data analysis that the C3 Work Package (WP) will perform in support of the Access 5 Step 1 C3 flight demonstration objectives as well as the processes that will be used by the Flight IPT to gather and distribute the data collected to satisfy those objectives. In addition to C3 requirements, this document will encompass some Human Systems Interface (HSI) requirements in performing the C3 flight demonstrations.

The C3 DAP will be used as the primary interface requirements document between the C3 Work Package and Flight Test organizations (Flight IPT and Non-Access 5 Flight Programs). In addition to providing data requirements for Access 5 flight test (piggyback technology demonstration flights, dedicated C3 technology demonstration flights, and Airspace Operations Demonstration flights), the C3 DAP will be used to request flight data from Non-Access 5 flight programs for C3 related data products.

2 Data Requirements and Analysis

Data collection and analysis requirements are described for each of the Access 5 Step 1 C3 flight demonstration objectives in the following paragraphs. The General Test Objectives (GTOs) and their corresponding Specific Test Objectives (STOs) have traceability to one or more of the functional requirements (see Appendix A) defined in either the *HALE UAS Command and Control Communications Step 1 Functional Requirements Document* or the *HALE UAS ATC Communications Step 1 Requirements Document*. The functional requirements listed in Appendix A are a subset of the overall functional requirements in both documents, thus only the functional requirements that are listed as “Demo” under the “Verification Method” are used in the C3 DAP. Both functional requirements documents were developed by the ACCESS 5 C3 Work Package 6 effort.

While general data requirements are included here, specific parameter requirements are listed in Appendix B. This list shall be reviewed and developed with Host (unmanned vehicle or optionally piloted vehicle) and Air Vehicle Control Station (AVCS) responsible agents to assure implementation. It shall subsequently be reviewed and approved by the C3 Work Package lead and the Flight Demo IPT lead prior to demonstration flights.

The Flight IPT’s only responsibility is to provide data to the C3 work package.

All data must be Global Positioning Satellite (GPS) time-stamped (millisecond resolution is preferred) to allow correlation of data from the various data sources. All GPS time-stamping should be set to Zulu time to avoid the confusion of various local times.

The results of the data analysis will be included in the C3 Flight Demonstration Report.

A notional C3 flight demo architecture is shown in Figure 1. Not all links of the architecture are required to conduct C3 demonstration flights. Other C3 flight architectures are possible and they are left to the C3 hardware vendors and the vehicle system manufacturers to define.

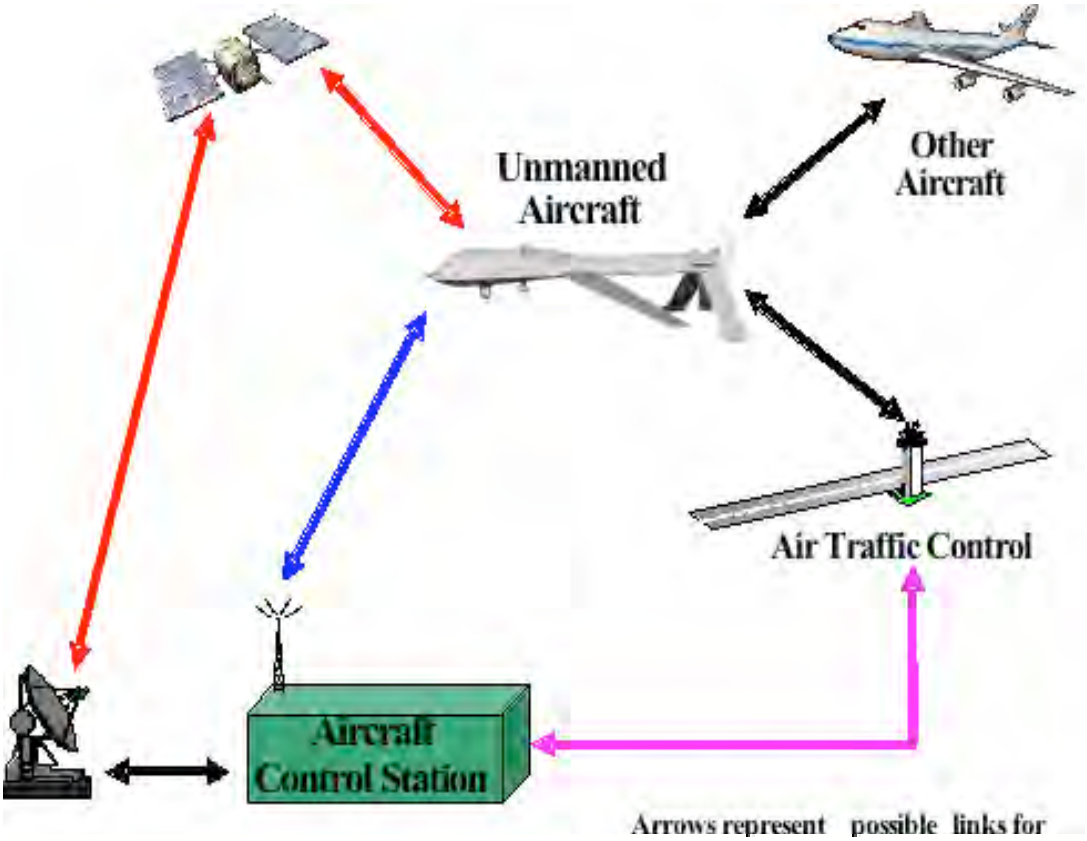

Figure 1, Notional C3 Flight Demo System Architecture

2.1 GTO 1: Assess the voice communication link between the Unmanned Aircraft System (UAS) pilot and Air Traffic Control (ATC) for both Line of Sight (LOS) and Beyond Line of Sight (BLOS) operations

2.1.1 STO 1-1: Evaluate the delay in the voice communication link between the UAS pilot and the ATC controller when the Unmanned Aircraft (UA) is using a LOS link with the AVCS

- **Measures of Performance:** Voice transmission delay time. Measure the bi-directional time delay of voice communications between the UA pilot in the AVCS and the ATC controller.
  - **Success Criteria:** Acquire data to measure time delay in ATC voice communications.
  - **Data Requirements:**
    - Time-tagged recordings of UA pilot transmissions at the AVCS and corresponding ATC receptions
    - Time-tagged recordings of ATC transmissions and corresponding AVCS receptions
    - UA pilot and ATC controller questionnaires (HSI questionnaire)
  - **Final Data Products:**
    - Plot of voice transmission delay time samples
    - UA pilot and ATC controller evaluations
- **C3 DAP Requirements:** 1.1, 1.2, and 1.4 (As defined in Appendix A)

2.1.2 STO 1-2: Evaluate the quality of the voice communication link between the UAS Pilot and ATC when the UA is using the LOS link with the AVCS

- **Measures of Performance:** Quality of service. Evaluate the quality of the voice transmission received by ATC and that received by the UAS pilot.
  - **Success Criteria:** Acquire data to evaluate voice transmission.
  - **Data Requirements:**
    - Voice recordings at the controller station and UA AVCS
    - Pilot and controller Mean Opinion Score (MOS) questionnaires (HSI questionnaire)
  - **Final Data Products:**
    - C3 WP analysis of the voice recordings
    - UA pilot and ATC controller MOS summary
- **C3 DAP Requirements:** 1.1, 1.2, and 1.4 (As defined in Appendix A)

2.1.3 STO 1-3: Evaluate the delay in the voice communication link between the UAS pilot and the ATC controller when the UA is using the BLOS link with the AVCS

- **Measures of Performance:** Voice transmission delay time. Measure the bi-directional time delay of voice communication between the UA pilot in the AVCS and the ATC controller.
  - **Success Criteria:** Acquire data to measure time delay in ATC voice communications.
  - **Data Requirements:**
    - Time-tagged recordings of UA pilot transmissions at the AVCS and corresponding ATC receptions
    - Time-tagged recordings of ATC transmissions and corresponding AVCS receptions
    - UA pilot and ATC controller questionnaires (HSI questionnaire)
  - **Final Data Products:**
    - Plot of voice transmission delay time samples
    - UA pilot and ATC controller evaluations
- **C3 DAP Requirements:** 1.1, 1.2, and 1.4 (As defined in Appendix A)

2.1.4 STO 1-4: Evaluate the quality of the voice communication link between the UAS Pilot and ATC when the UA is using the BLOS link with the AVCS

- **Measures of Performance:** Quality of service. Evaluate the quality of the voice transmission received by ATC and that received by the UAS pilot.
  - **Success Criteria:** Acquire data to evaluate voice transmission.
  - **Data Requirements:**
    - Voice recordings at the controller station and UA AVCS
    - Pilot and controller Mean Opinion Score (MOS) questionnaires (HSI questionnaire)
  - **Final Data Products:**
    - C3 WP analysis of the voice recordings
    - UA pilot and ATC controller MOS summary
- **C3 DAP Requirements:** 1.1, 1.2, and 1.4 (As defined in Appendix A)

2.2 GTO 2: Assess the command and control (C2) links between the AVCS and the UA for both LOS and BLOS operations

2.2.1 STO 2-1: Evaluate the C2 link bandwidth usage during UA operations

- **Measures of Performance:** Bandwidth. Evaluate the C2 link bandwidth usage characteristics for UA operations.
  - **Success Criteria:** Acquire C2 link bandwidth usage data for duration of LOS and BLOS operations.
  - **Data Requirements:**
    - LOS mean throughput rate vs. time
    - BLOS mean throughput rate vs. time
  - **Final Data Products:**
    - LOS bandwidth usage characteristics vs. time (uplink and downlink)
    - BLOS bandwidth usage characteristics vs. time (uplink and downlink)
- **C3 DAP Requirements:** 2.1 through 2.4 (As defined in Appendix A)

2.2.2 STO 2-2: Evaluate the C2 link performance when the UA is using the LOS link with the AVCS

- **Measures of Performance 1:** Signal integrity. Evaluate the LOS C2 link bit error rate (BER).
  - **Success Criteria:** Acquire BER data measured for duration of LOS operations.
  - **Data Requirements:** LOS C2 link BER vs. time.
  - **Final Data Products:** BER characteristics for LOS C2 link.
- **Measures of Performance 2:** LOS C2 link availability/continuity. Evaluate the LOS C2 link availability/continuity when the UA is operating within LOS of the AVCS.
  - **Success Criteria:** Acquire C2 link availability/continuity data for duration of LOS operations. The link availability/continuity can be characterized by successful message transfer rates.
  - **Data Requirements:**
    - LOS C2 link availability/continuity vs. location vs. time
    - LOS C2 link prediction
  - **Final Data Products:**
    - LOS C2 link availability/continuity percentage
    - LOS C2 link dropouts vs. location, relative to the AVCS
    - LOS C2 link dropout reasons vs. time
- **C3 DAP Requirements:** 2.6 through 2.9 (As defined in Appendix A)

2.2.3 STO 2-3: Evaluate the C2 link performance when the UA is using the BLOS link with the AVCS

- **Measures of Performance 1:** Signal integrity. Evaluate the BLOS C2 link bit error rate (BER) using pre-defined data packets to perform the BER test.
  - **Success Criteria:** Acquire BER data measured for duration of BLOS operations.
  - **Data Requirements:** BLOS C2 link BER vs. time.

- **Final Data Products:** BER characteristics for BLOS C2 link.

❖ **Measures of Performance 2:** BLOS C2 link availability/continuity. Evaluate the BLOS C2 link availability/continuity when the UA is operating BLOS of the AVCS.

- **Success Criteria:** Acquire C2 link availability/continuity data for duration of BLOS operations. The link availability/continuity can be characterized by successful message transfer rates.
- **Data Requirements:**
  - ♦ BLOS C2 link availability/continuity vs. time
  - ♦ BLOS C2 link dropouts vs. UA antenna look angle vs. time
  - ♦ Satellite footprint prediction
- **Final Data Products:**
  - ♦ BLOS C2 link availability/continuity percentage
  - ♦ BLOS C2 link dropouts vs. location, relative to the AVCS
  - ♦ BLOS C2 link dropout reasons vs. time

❖ **C3 DAP Requirements:** 2.6 through 2.9 (As defined in Appendix A)

2.2.4 STO 2-4: Evaluate the timeline data of message transfers when the UA is using the LOS link with the AVCS

❖ **Measures of Performance:** End-to-end message transfer delay. Evaluate the bi-directional message transfer delay and prioritization between the AVCS and the UA.

- **Success Criteria:** Acquire message transfer delay data measured for duration of LOS operations.
- **Data Requirements:**
  - ♦ Uplink message transfer delay vs. time
  - ♦ Downlink message transfer delay vs. time
- **Final Data Products:** Various end-to-end LOS message transfer delay statistics, including priority, that shall correlate with flight status or events.

❖ **C3 DAP Requirements:** 2.5 through 2.9 (As defined in Appendix A)

2.2.5 STO 2-5: Evaluate the timeline data of message transfers when the UA is using the BLOS link with the AVCS

❖ **Measures of Performance:** End-to-end message transfer delay. Evaluate the bi-directional message transfer delay and prioritization between the AVCS and the UA.

- **Success Criteria:** Acquire message transfer delay data measured for duration of BLOS operations.
- **Data Requirements:**
  - ♦ Uplink message transfer delay vs. time
  - ♦ Downlink message transfer delay vs. time
- **Final Data Products:** Various end-to-end BLOS message transfer delay statistics, including priority, that shall correlate with flight status or events.

❖ **C3 DAP Requirements:** 2.5 through 2.9 (As defined in Appendix A)

2.2.6 STO 2-6: Evaluate the security of the access to the C2 link

- **Measures of Performance:** Effectiveness of access control.
  - **Success Criteria:** Acquire C2 information exchanges between UA and AVCS over the duration of the flight.
  - **Data Requirements:**
    - Access packets and protocols
    - Response packets with respect to access packets
  - **Final Data Products:** Histogram and data analysis of message transfer by all UA's, AVCS, and ATC constituents.
- **C3 DAP Requirements:** 2.1 through 2.9 (As defined in Appendix A)

2.3 Additional C3 Data and Test Requirements

2.3.1 Test Condition Data

Record day of flight test conditions such as weather conditions, location, and other environmental information during the flight test. Also record the ATC communications and C2 frequencies used during the test.

2.3.2 Testing Capabilities

- Provide adjustment capability for transmission power.
- Provide adjustment capability for artificial link delay.

2.4 HSI Test Requirements

2.4.1 Control Room Requirements

- Provide real-time monitoring of ATC transmissions and receptions
- Provide a location, near the AVCS, for a HSI representative to observe the flight operations
  - To observe pilot actions
  - To hear and understand pilot speech
  - To see and comprehend AVCS displayed data

2.4.2 Flight Test Requirements

The General Test Objectives and Specific Test Objectives for the following requirements shall be defined by the HSI WP during the flight test planning process.

- Demonstrate the pilot interface to aircraft trajectory display and control above FL430
- Demonstrate the pilot interface to voice communications display and control to and from ATC above FL430
- Demonstrate the pilot interface to data link system display and control above FL430
- Demonstrate the pilot interface to navigation display and control above FL430

3 Data Collection and Distribution

3.1 Data Recording

Data will be recorded at the following sources:

3.1.1 UAS Data System

The Flight IPT shall coordinate with the UAS vendor to ensure proper data recording of the downlink and uplink telemetry data stream between the UA and the AVCS at the ground station.

3.1.2 AVCS Video System

The Flight IPT shall coordinate with the UAS vendor to ensure proper video recording of the downlink video stream between the UA and the AVCS at the ground station. The recorded video shall contain GPS time in the video. In addition, audio communications between the UA pilot and ATC controller shall be recorded on the audio track of the video recording.

3.1.3 Operator Questionnaires

HSI WP lead shall coordinate with C3 WP lead in generating a HSI/C3 questionnaire to be used during the flight demonstrations. HSI representatives shall provide and administer the HSI/C3 questionnaires after every flight to the target audience. HSI WP shall provide to the C3 WP a copy of the completed questionnaires.

3.2 Data Integrity

The Flight IPT shall coordinate with the UAS vendor (data collector) to ensure that data is being collected and further that data is not corrupted or missing. Data integrity shall be verified prior to flight to assure hardware/software and the supporting systems are sound and products are accurate, complete, and reliable.

3.3 Data Transfer to Flight IPT

The Flight IPT Data Manager will interface with a Point of Contact (POC) for each of the sources. The Flight IPT shall specify where and for how long the raw data will be stored and whether or not the data source will keep copies of processed data.

All data processing by all parties should ensure that all parameters are processed at their acquired sample rates and not at reduced rates.

The collector of data (e.g. UA and AVCS, etc.) is responsible for storage, transfer and retrieval of data until such time that it has successfully been received by NASA/DFRC as determined by NASA/DFRC. From that time forward NASA/DFRC shall be responsible for the maintenance and further dissemination of data. Transferred data from the collector of data shall be in the format defined below, so that it can be communicated and transferred to NASA/DFRC for subsequent control, storage, retrieval and dissemination by the Access 5 Flight IPT to responsible data analysis engineer(s) within the C3 workgroup.

Format and media: Semi-colon delimited ASCII text file on a CD-ROM or DVD

Address to ship media: NASA Dryden FRC
Attn: ***TBD (Flight IPT Data Manager)*** Mail Stop ***TBD***
Whse #6 Bldg 4876
Edwards, CA 93524

The UA and AVCS organizations shall be responsible for determining their data management organization. In each case, however, a central point of contact shall be identified to the Flight IPT. Requests for data shall be processed through written request (email acceptable) to the Flight IPT.

The Flight IPT Data Manager is ***TBD, phone number TBD***.

Raw data shall be recorded, stored, and transferred to NASA/DFRC by data collector separate from any converted data, unless agreed otherwise by Flight IPT.

3.4 Data Storage and Distribution

The Flight IPT shall retain and distribute all data products from the flight demonstrations. The C3 WP shall submit a written request to the Flight IPT for all requested data products. The requested data products shall be delivered to the C3 WP to the specified person/organization, in the data format and media, listed on the data request.

The data processes consist of identification, collection, telemetry, recording, storage, transfer/communication, retrieval and processing. Prior to flight demo all required data shall be identified in this Data Analysis Plan, Appendix B.

NASA/DFRC shall maintain data in the same format as provided by data collectors. NASA/DFRC may elect to further convert and will thereafter separately maintain/store products to assure integrity of original data.

3.5 Data Restrictions

Data nor analysis may not be copied, transferred or otherwise provided to any person or entity without the written approval of the Flight IPT.

Data shall not be transferred via internet without prior approval of the Flight IPT.

Data restrictions as defined by Federal law or Access 5 are not modified or deleted by this data plan. They apply in full.

4 Reference Documents

C3 Test Objectives

HALE UAS Command and Control Communications Step 1 Functional Requirements Document

HALE UAS ATC Communications Step 1 Requirements Document

5 Acronyms

The following definitions are applicable to this project and this document.

ATC	Air Traffic Control
AVCS	Air Vehicle Control Station
BER	Bit Error Rate
BLOS	Beyond Line-of-Sight
C2	Command and Control
C3	Command, Control, and Communication
DAP	Data Analysis Plan
DFRC	Dryden Flight Research Center
FAA	Federal Aviation Administration
GPS	Global Positioning Satellite System
GTO	General Test Objective
HALE	High-Altitude Long-Endurance
HIS	Human Systems Interface
IPT	Integrated Product Team
LOS	Line-of-Sight

MOP	Measure of Performance
MOS	Mean Opinion Score
NAS	National Air Space
NASA	National Aeronautics and Space Administration
OPV	Optionally Piloted Vehicle
POC	Point of Contact
STO	Specific Test Objective
T/M	Telemetry
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
WP	Work Package

Appendix A.1 – Functional Requirements for ATC Communications

C3 DAP Requirement Number	Requirement Title [or Requirement Statement]	Originating Document Requirement Number (Section Number)
	FUNCTIONAL REQUIREMENTS	
1.1	Tune to Assigned Channel	4.2.1
1.2	Monitor/Receive ATC Voice Channel Activity	4.2.2
1.3	Transmit Indication Signal	4.2.3
1.4	Transmitting Voice	4.2.4
1.5	Transmitting Only During Transmit Signal Indication	4.2.5
1.6	Entry Into a Talk Group	4.2.6
1.7	Coexistence with other Existing NAS Systems	4.2.7
1.7.1	[...shall not generate harmful interference to other NAS systems.]	4.2.7.a
1.7.2	[...shall operate under the existing RFI environments.]	4.2.7.b

The originating document for the above functional requirements is *HALE UAS ATC Communications Step 1 Requirements Document*, Version 3.0, Dated 31May2005.

Appendix A.2 – Functional Requirements for Command and Control

C3 DAP Requirement Number	Requirement Title [or Requirement Statement]	Originating Document Identifier Number (Section Number)
	FUNCTIONAL REQUIREMENTS	
2.1	The C2 Communications System shall exchange situation awareness data.	4.3.3.1.a
2.2	The C2 Communications System shall exchange UA health and status data.	4.3.3.1.b
2.3	The C2 Communications System shall exchange en route flight data.	4.3.3.1.c
2.4	The C2 Communications System shall exchange command and control messages.	4.3.3.2.a
2.5	In the C2 Communications System, information regarding safety of flight shall have the highest priority.	4.3.3.3.b
2.6	The C2 Communications System shall maintain the C2 link between the UA and the AVCS at all flight phases, including transition between LOS and BLOS.	4.3.5.1.a
2.7	The C2 Communications System shall allow scheduled and/or predictable C2 dropouts that result from physical constraints.	4.3.5.1.b
2.8	The C2 Communications System shall maintain the C2 link between the UA and the AVCS at all flight phases, including possible handover from one AVCS to another.	4.3.5.2.a
2.9	When more than one AVCS is deployed, the C2 Communications System shall provide a C2 link between each AVCS.	4.3.5.2.b

The originating document for the above functional requirements is *HALE UAS Command and Control Communications Step 1 Functional Requirements Document*, Version 3.01, Dated 10Jun2005.

Appendix B - Flight Data Parameter List

Appendix B – Flight Data Parameter List			Measurand Code	Source		Range (min – max)	Bit Count	T/M	Destination	Rate (Hz)	Objective
	Parameter Description (Engineering Unit)	Parameter Name									
	UA Latitude (deg:min:sec.hundredths)			GPS	UA			Yes			STO 1-1 to 2-6
	UA Longitude (deg:min:sec.hundredths)			GPS	UA			Yes			STO 1-1 to 2-6
	UA Altitude (ft MSL)			GPS	UA			Yes			STO 1-1 to 2-6
	UA Airspeed – X axis (KTAS)			GPS	UA			Yes			STO 1-1 to 2-6
	UA Airspeed – Y axis (ft/min)			GPS	UA			Yes			STO 1-1 to 2-6
	UA Airspeed – Z-axis (ft/min)			GPS	UA			Yes			STO 1-1 to 2-6
	Operator Video			AVCS Video				No			STO 1-1 to 1-4
	Operator Audio			AVCS Video				No			STO 1-1 to 1-4
	Operator Command Sent (nd)			AVCS Out				No			STO 2-2 to 2-6
	Operator Command Received (nd)			FMS	UA			Yes			STO 2-2 to 2-6
	UA C3 System Status			UA				Yes			STO 1-1 to 2-6
	AVCS System Status			AVCS				No			STO 1-1 to 2-6
	Uplink Bandwidth Utilization (KHz)			AVCS				No			STO 2-1
	Downlink Bandwidth Utilization (KHz)			AVCS				No			STO 2-1
	UA/AVCS Communication Status			AVCS				No			STO 1-1 to 2-6
	UA Signal Transmission Power Level (dB)			UA				Yes			STO 2-2 to 2-3
	AVCS Signal Transmission Power Level (dB)			AVCS				No			STO 2-2 to 2-3
	UA Signal Reception Power Level (dB)			UA				Yes			STO 2-2 to 2-3
	AVCS Signal Reception Power Level (dB)			AVCS				No			STO 2-2 to 2-3

Appendix B – Flight Data Parameter List			Measurand Code	Source		Range (min – max)	Bit Count	T/M	Destination	Rate (Hz)	Objective
	Parameter Description (Engineering Unit)	Parameter Name									
	Uplink Bit Error Rate			UA				Yes			STO 2-2 to 2-3
	Downlink Bit Error Rate			AVCS				No			STO 2-2 to 2-3
	Satellite Antenna Gimble Angle – Azimuth (Deg)			AVCS				No			STO 2-3
	Satellite Antenna Gimble Angle – Elevation (Deg)			AVCS				No			STO 2-3
	Data Relay Satellite in Use			AVCS				No			STO 1-3, 1-4, 2-3, 2-5, 2-6
	UA Pitch Rate (deg/sec)			GPS	UA			Yes			STO 1-1 to 2-6
	UA Yaw Rate (deg/sec)			GPS	UA			Yes			STO 1-1 to 2-6
	UA Roll Rate (deg/sec)			GPS	UA			Yes			STO 1-1 to 2-6
	UA Linear Acceleration – X axis (G)			GPS	UA			Yes			STO 1-1 to 2-6
	UA Linear Acceleration – Y axis (G)			GPS	UA			Yes			STO 1-1 to 2-6
	UA Linear Acceleration – Z-axis (G)			GPS	UA			Yes			STO 1-1 to 2-6
	UA Angular Acceleration – Pitch (deg/sec^2)			GPS	UA			Yes			STO 1-1 to 2-6
	UA Angular Acceleration – Yaw (deg/sec^2)			GPS	UA			Yes			STO 1-1 to 2-6
	UA Angular Acceleration – Roll (deg/sec^2)			GPS	UA			Yes			STO 1-1 to 2-6
	Angle of Attack (deg)			GPS	UA			Yes			STO 1-1 to 2-6
	Angle of Sideslip (deg)			GPS	UA			Yes			STO 1-1 to 2-6
	Total Temperature (degF)			GPS	UA			Yes			STO 1-1 to 2-6
	Static Pressure (psia)			GPS	UA			Yes			STO 1-1 to 2-6
	Total Pressure (psia)			GPS	UA			Yes			STO 1-1 to 2-6